PB-215 240

INSTRUMENTS FOR THE DETECTION AND IDENTIFICATION OF RADIOACTIVITY IN ENVIRONMENTAL MEDIA

Conrad P. Straub, et al

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1959

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INSTRUMENTS FOR THE DETECTION AND IDENTIFICATION OF RADIOACTIVITY IN ENVIRONMENTAL MEDIA

A brochure describing the instrumentation available at the Robert A. Taft Sanitary Engineering Center for surveillance operations, research, and training.

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
BUREAU OF STATE SERVICES
Division of Radiological Health

Robert A. Taft Sanitary Engineering Center
Cincinnati 26, Ohio

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Introduction

This brochure describes and illustrates the variety of instruments available at the Center for measurement of radioactivity in various environmental media. Shown are instruments that may be used for the measurement of gross radioactivity; those for measuring specific kinds of radioactivity as from alpha, beta, or gamma emitters; and instruments such as the gamma spectrometer for identification of specific radionuclides.

The instrumentation shown is located in two counting rooms, one used for surveillance counting, and the other for very low level and specific radionuclide counting. The surveillance counting room is equipped with the internal gas-flow proportional counters, the large area end-window air sample counter, one of the shielded converters for routine surveillance use, and two internal proportional gas-flow counters and a 20-channel pulse height analyzer for use by the research staff.

A low level counting room was constructed for the housing of much of the specialized equipment including the 20 and 100-channel pulse height analyzers, the low background beta (anti-coincidence) counter, and the Tri-Carb liquid scintillation counter.

The overall cost of equipment available to the Research Activities totals more than $90,000, of which approximately one third has been obtained with AEC contract funds. (Contract No. AT-(49-5)-1288).

Figure 1. Overall view of counting room - second floor, Robert A. Taft Sanitary Engineering Center.

COUNTING ROOM

Figure 1 shows an overall picture of the newly expanded counting room on the second floor of the Sanitary Engineering Center. Along the left wall is a shielded Geiger tube and scaler, and a second scaler associated with the 7-1/2" end window counter used for air sample counting. Internal proportional counters and converters, used for alpha and beta counting, are lined along the back wall. One of these counters is equipped with a lead shield to reduce background. The instrument on the right is a 20-channel gamma spectrometer. The part of the "L" shaped room not visible in the picture provides space for a work table and sample storage. More storage space is provided behind the cameraman, and the entrance to the room is to the left just outside the picture.

INTERNAL PROPORTIONAL COUNTERS

Because they offer 2π geometry, internal proportional counters are very useful for low counting rates. They may be used for counting alpha particles and alpha plus beta activity by a suitable selection of operating voltages. The sample chamber, shown in Figure 2, is 2-1/4" in diameter.

The instrument has a background of less than 0.1 counts/minute in the alpha region and approximately 50 counts/minute in the beta region. The gas used for proportional counting is 90% argon, 10% methane, and is available commercially.*

The instrument can be purchased as a complete unit which has a 2500 volt power supply, preamplifier, timer, register, and scaler. A proportional counter converter is also available which includes the chamber and the preamplifier. This unit can be used with most scaling units.

*The Matheson Co., Inc., East Rutherford, N. J.

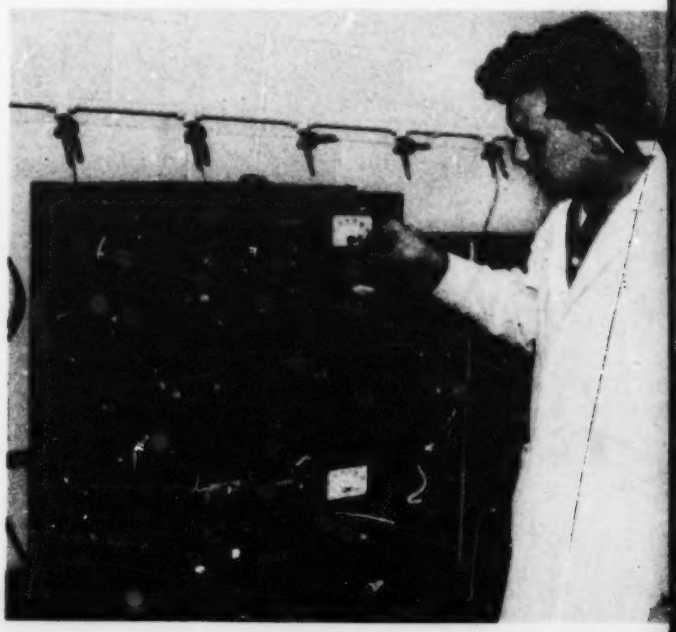

Figure 2. Internal proportional counters for measurement of alpha, beta, and gamma activity.

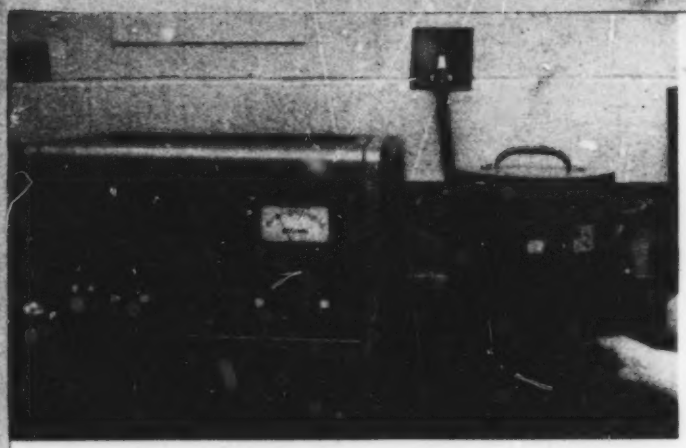

Figure 3. Geiger-Müller counter for measurement of beta-gamma activity.

GEIGER COUNTER IN LEAD SHIELD

The Geiger counter is used to detect beta-gamma activity levels particularly in tracer studies. It does not require elaborate sample preparation, and the Geiger tube can count relatively high activity levels because the geometry can be varied. However, "dead-time" losses must be corrected for, since they are substantially larger than in the proportional counter. As shown in Figure 3, the sample is inserted in a lead shield to reduce the background to approximately 30 cpm for the 1-1/4" diameter tube used. In some instances, thin window tubes are used for alpha detection, and tubes more sensitive to gamma radiation are available.

A high voltage supply of at least 1500 volts is needed for the G-M counter. The pulses are relayed on the same cable and no preamplifier is required.

END WINDOW GEIGER COUNTER AUTOMATIC SAMPLE CHANGER

This counter (Figure 4) has the capacity of counting 24 samples consecutively, repeating the procedure until stopped. Background levels have been constant at 15 or 16 cpm. Counts can be controlled according to time or total counts. The results are recorded on a readout tape as the total count in a given interval of time or as the time interval required to register a predetermined number of counts.

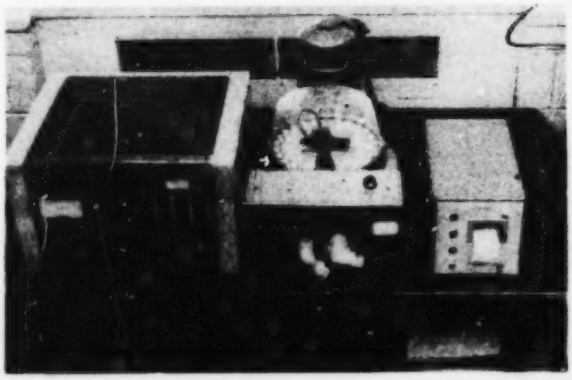

Figure 4. End window Geiger-Müller counter with automatic sample changer.

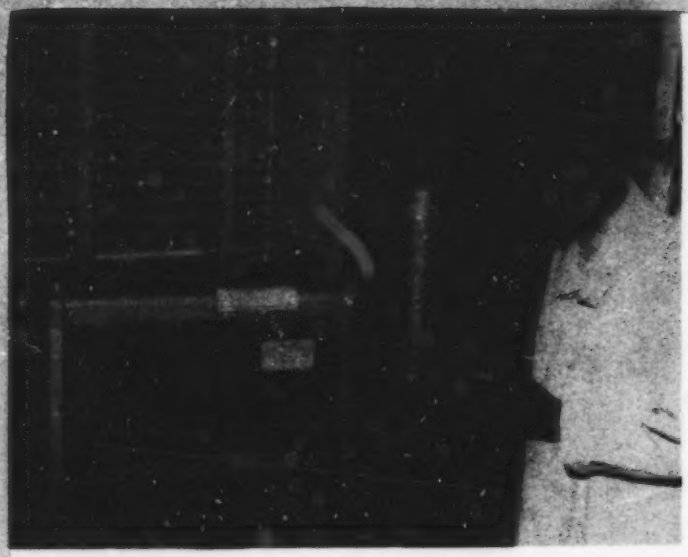

Figure 5. Scintillation counter for measuring alpha activity.

ALPHA SCINTILLATION COUNTER

Depending on the phosphor employed, alpha, beta, or gamma activity may be counted in this instrument (Figure 5). It is used as an alpha counter with a zinc sulfide screen and a 6292 Dumont photomultiplier tube. As shown in the illustration, the sample is placed on a platform which screws into the base for adjustment of sample height. It is connected to a scaler having at least 2000 volts power supply. The power requirements for the preamplifier in the counter are: 6.3 volts A.C. for the filament, and 75 - 180 volts at about 5 milliamperes for the plate. Most scalers have these power requirements.

The scintillation counter is very sensitive to alpha particles and requires no special sample preparation as is the case with the internal proportional counter. It is used for determining the radon daughter product activities in air samples and has an optimum geometry of greater than 45 per cent. Background levels for alpha counting amount to less than 0.5 cpm.

LARGE END WINDOW COUNTER

An end window proportional counter 7-1/2" in diameter is used to count the large filter samples collected by the National Air Sampling Network. The filters, having an active area 7" by 9", are placed directly under the thin Mylar window as shown in Figure 6. The chamber is equipped with seven wire loops for the high voltage, and P-10 gas (90% argon, 10% methane) is used for flushing.

Although primarily for gross beta-gamma counting of deposited air particulate activity, the counter has been used with other large area samples. Self-absorption losses are reduced because the samples can be spread over this large area, and sample preparation is simplified.

The converter (a jointly mounted chamber and preamplifier) is connected to a scaler having a voltage supply of at least 2500 volts and appropriate voltages to power the preamplifier (6.3 volts A.C. at 1.5 amps; 250-300 volts D.C. at 20 ma; 150-200 volts D.C. regulated at 8 ma). Most commercially available scalers have these voltages.

Figure 6. Large area end window proportional counter for measuring activity in air particulates.

4π FLOW COUNTER

The 4π counter (Figure 7) is used primarily to standardize solutions used to calibrate other instruments. Consequently it is not employed as a routine counter, but it is useful for counting isotopes having a large variety of beta energies. This counter eliminates backscatter corrections necessary in the 2π flow counter. The sample to be counted is deposited on a very thin sheet of plastic (Mylar), coated on both sides with a vapor of aluminum to make it a conducting surface, or on a very thin plastic film (Formvar E or Zapon) of small diameter. Any radiations penetrating the Mylar will be counted in either the upper or lower chamber.

A high voltage center wire with separate leads is mounted at the top of each chamber. It is therefore possible to count from each chamber separately, enabling corrections to be made for absorption losses through this very thin (< 1.0 mg/cm^2) sample holder.

The counter operates in either the Geiger region or the proportional region, depending on the gas used.

Higher counting rates are possible with P-10 gas because of its shorter resolving time than that of helium-isobutane (Geiger) gas. The background, using both chambers simultaneously, is about 70 cpm.

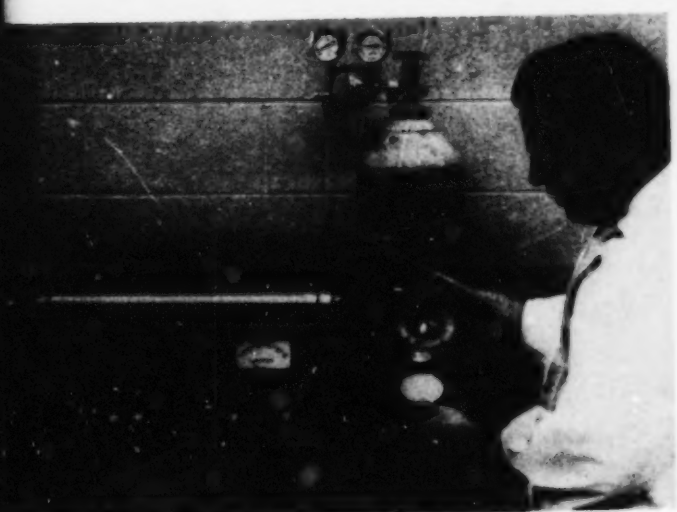

Figure 7. Four Pi flow counter for calibrating radioactive solutions.

The power requirement for this counter includes a 5000 volt power supply for operation in the proportional region with various counting gases (certain gases such as P-10 will allow counter operation at 3000 volts or less). The remaining requirements are satisfied by most commercially available scalers.

LOW BACKGROUND BETA (ANTI-COINCIDENCE) COUNTER

The low background beta (anti-coincidence) counter has two very thin window (0.9 mg/cm^2) Geiger tubes as the central counters. These require a continuous gas flow because of gas leaks through the very thin windows. This counter is designed for counting samples which are very low in activity, as low as 1 disintegration per minute. This sensitivity is possible because the background is about 0.5 counts per minute.

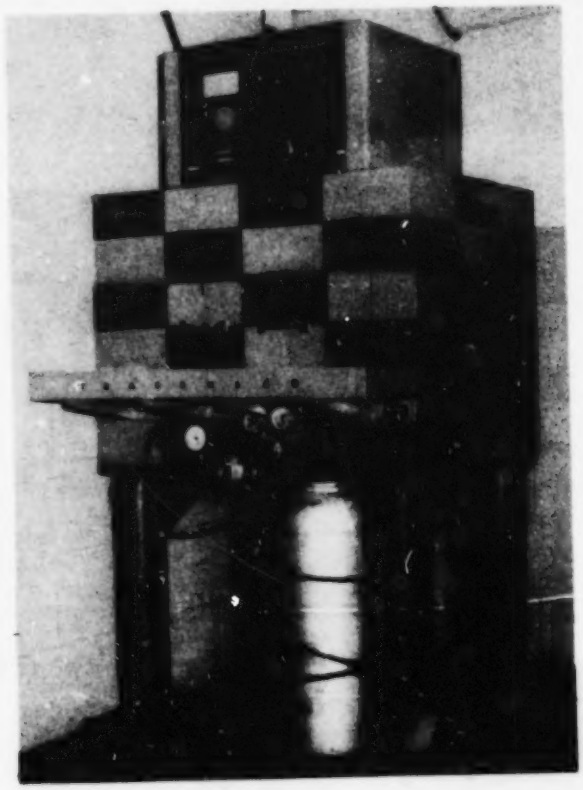

Figure 8. Exterior view of low background anti-coincidence beta counter.

This low background is achieved by 2-1/2 tons of steel (see Figure 8) and a cosmic ray umbrella of eleven Geiger tubes in a semi-cylindrical arrangement over the central counters. When a cosmic ray passes through the umbrella it cannot be recorded as an event in the central counter but is electronically eliminated as a potential count. The gamma rays present in the air are stopped by the steel which surrounds the entire counter system.

Figure 9. Interior view of low background anti-coincidence beta counter showing sample chamber and anti-coincidence umbrella.

The central counters, shown in Figure 9, have 1.3 inch diameter window openings and are separated by a 1-inch wall of mercury to minimize "cross talk" between the detectors. Each tube has its own scaler, as does the umbrella ring on top.

STEEL SHIELD

This four-ton massive six-inch steel shield shown in Figure 10, is located in the Low Level Counting Room. It was laminated of one-inch plate steel. Before use the steel plate had to be sand blasted to remove surface contamination from fallout. Outside dimensions of the shield are 30" x 30" x 36", inside dimensions 18" x 18" x 24". It is supported on 4" steel pipes. The door, weighing approximately 1 ton, is supported by three large hinges and swings quite freely.

A 4" x 4" NaI (Tl activated) crystal and 5" photomultiplier tube is attached to the inside face of the door. Background is comparable to a 2" x 2" solid NaI crystal with 1-3/4" of lead shielding.

Shown at the foot of the shield are two small pigs made at SEC. The light colored one is for a 2" well crystal, the dark one is for a 2" solid crystal. These can be attached to the analyzer in the background.

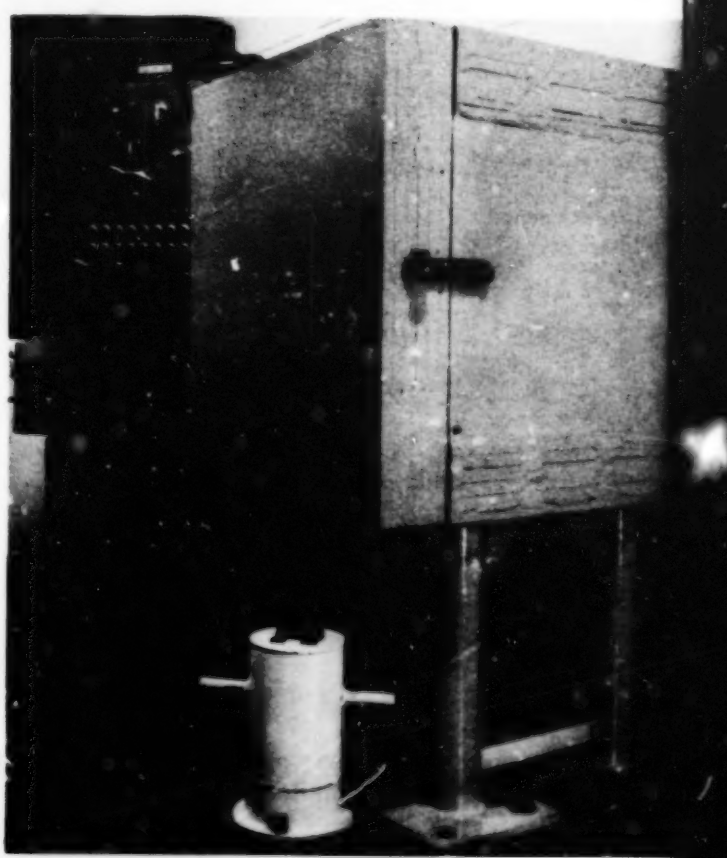

Figure 10. Steel shield for use with gamma spectrometers.

FOUR INCH NaI (Tl) CRYSTAL FOR GAMMA DETECTION

The large 4" x 4" solid sodium iodide (thallium activated) crystal shown in Figure 11 to be used with a pulse height analyzer is mounted on a 5" Dumont #6364 phototube. Because of its size, high energy gammas (range 2-5 Mev) may be captured thus extending the range of operation of our gamma spectrometers. Furthermore, the efficiency of detection of gamma radiations up to 2 Mev (which covers most of the radiations from mixed fission products and common induced activities) is very much greater than with a common 2" x 2" crystal.

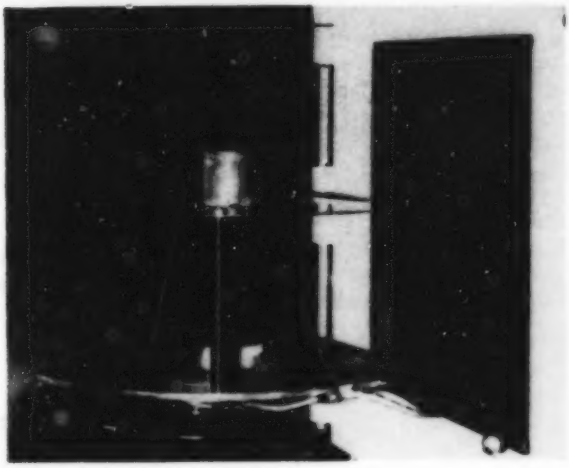

Figure 11. Interior view of steel shield showing 4" solid NaI (Thallium activated crystal) and 5" photomultiplier tube assembly attached to door of steel shield.

To shield the detector from gamma rays in the air the unit is housed in a 6-inch steel shield having inside dimensions of 18" x 18" x 24" (see Figure 10).

Specially designed beakers surround the crystal to give optimum geometry for liquid samples up to 3.5 liters in volume. Smaller liquid samples and solid samples may be counted by placing them directly on top of the crystal.

GAMMA PULSE HEIGHT ANALYSERS

The basis for gamma spectrometry is the emission of gamma photons in a characteristic line spectrum consisting of a few discrete energies. The utilization of these spectra for the identification of specific radionuclides requires detectors capable of an output proportional to the gamma energy.

Gamma photons interact with matter in any of three ways, two of which are of importance in gamma spectroscopy. The interactions may produce a secondary (photo) electron carrying the full gamma energy; they may produce a secondary (Compton) electron carrying less than the full gamma energy plus a secondary gamma photon; or, less important, they may produce a positron-electron pair. The secondary electrons transfer their energy to the electrons within the crystal which are excited and in the de-excitation process release light quanta proportional to the energy of the incident gamma radiation. By the use of suitable light-collecting and electronic apparatus, a pulse is obtained which is proportional to the amount of energy lost by the incident gamma photon in the crystal.

Almost all gamma spectroscopy systems now use a thallium activated sodium iodide crystal, a photomultiplier tube, and a linear amplifier to produce a pulse proportional to the gamma energy. The resulting pulses are then usually fed into a unit which (1) responds to all pulses larger than a preset value (integral discriminator), (2) responds to all pulses between two preset values (single channel analyzer), or (3) sorts pulses into a number of channels depend-

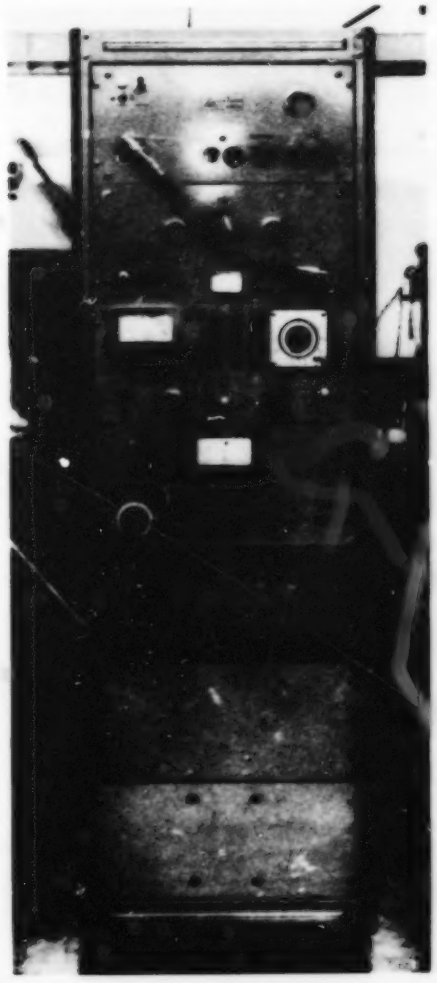

Figure 12. Single channel pulse height analyzer.

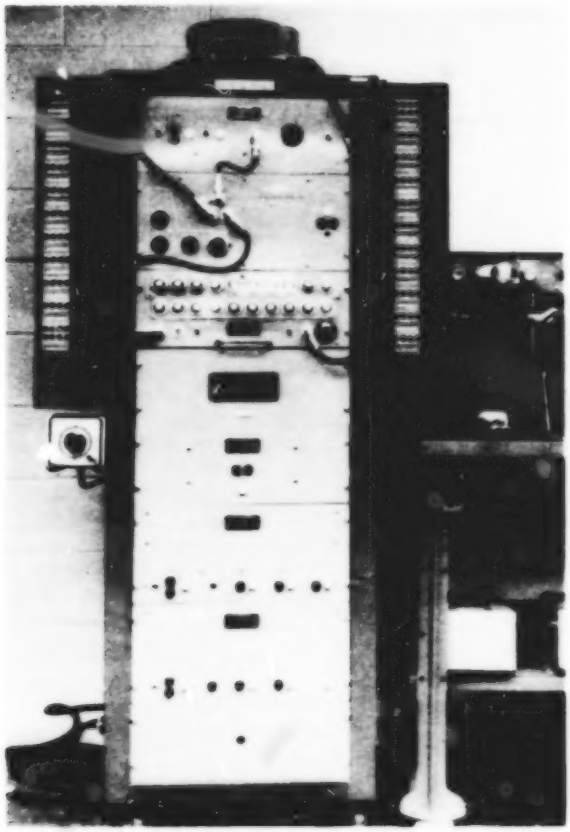

Figure 13. 20-Channel pulse height analyzer.

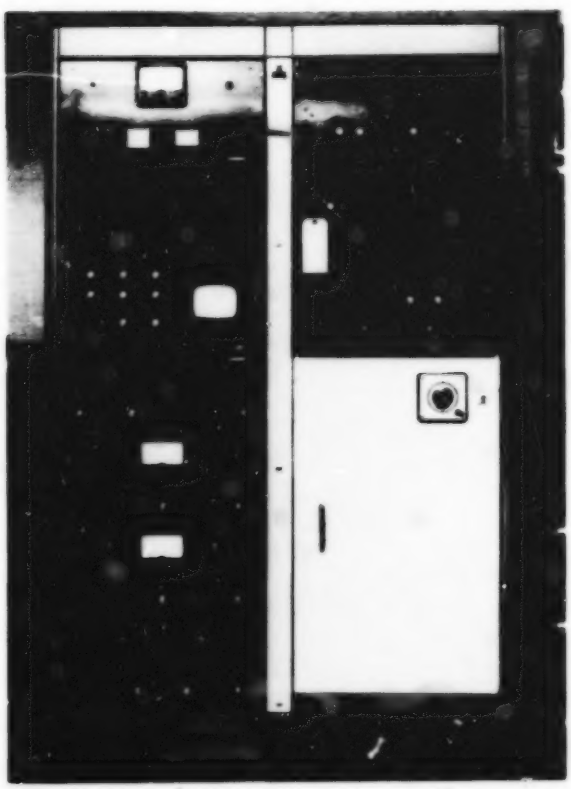

Figure 14. 100-Channel pulse height analyzer.

ing on their size (multichannel analyzer). Figures 12, 13, and 14 illustrate a single-channel, a 20-channel and a 100-channel analyzer, respectively. The full spectrum can be obtained with any of these instruments. The multichannel analyzer gives the full spectrum in a single run or a few runs; the single-channel analyzer requires a channel-by-channel plot, and the discriminator requires plotting of the difference between consecutive counts.

Gamma spectroscopy offers a means of simplifying the identification of specific radionuclides. Furthermore, because gamma radiation is affected by self-absorption to only a very minor degree, this technique permits the utilization of large samples with much less stringent sample preparation techniques than are required for alpha and beta counting. It must be remembered, however, that a number of the more important radionuclides, including strontium 90, strontium 89, yttrium 91, phosphorus 32, and hydrogen 3, either do not emit gamma radiation or do so only in a small percentage of the radioactive disintegrations. Gamma measurements also appear to be somewhat less sensitive than alpha or beta measurements, and there is some interference of one gamma radiation with another in complex mixtures.

LIQUID SCINTILLATION SPECTROMETER

The liquid scintillation spectrometer is used for counting very weak beta particles, especially tritium and carbon-14. Beta particles associated with these isotopes are very soft, and therefore difficult to count by ordinary means.

The unit employed at the Center consists of a light-tight, optical sampling chamber with convenient shutter mechanism and two photomultipliers shielded by two inches of lead in all directions, and placed in a 13-cubic foot freezer chest.

By having two photomultipliers "look at" the sample bottle containing the solution of radioactive sample and liquid scintillator, legitimate light pulses are seen simultaneously by both. An electronic coincidence circuit is provided to pass such pulses and to reject thermionic noise pulses which occur at random in the two photomultipliers and only very rarely chance to coincide in time. There are practically no counts contributed to the background from this source (2 or 3 cpm). This type of background must be sharply differentiated from "true" background due to cosmic rays and local extended gamma radiation.

The idea of liquid scintillation counting is simply to put the sample in solution with a liquid scintillator, thus giving essentially 100 per cent geometry and no self-absorption. Dilute solutions of fluorescent substances in aromatic solvents are useful as scintillation detectors.

The unit may be used to differentiate between two isotopes if their energies differ by a factor of at least six. Thus, it is possible to count tritium (maximum energy 0.018 Mev) and carbon-14 (maximum energy 0.115 Mev) and to record the respective counts in separate channels. When used in this manner, the unit is referred to as a two-channel analyzer.

The analyzer is installed in a room without fluorescent light. This is important since fluorescent light activates the K^{40} in glass thus increasing the background appreciably. After exposure to fluorescent light, the sample must be stored in the dark for at least 8 hours before the activated K^{40} dies out. The use of incandescent light avoids this difficulty.

The complete assembly of analyzer, freezer, and detector comes as a packaged unit and is ready for use without additional equipment.

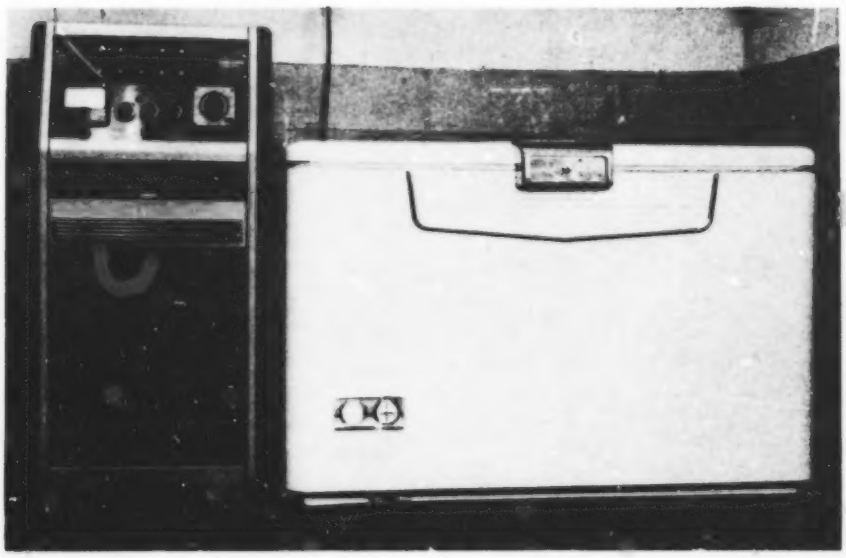

Figure 15. Liquid scintillation spectrometer - exterior view.

Figure 15 shows the complete assembly with the analyzer at the left and the freezer chest at the right. The detector assembly is shown in Figure 16. The two photomultiplier tubes are at each end of the assembly, and the sample is placed in the central sample container and covered with the hinged shield flap. The sample container is completely housed in a 2" lead shield.

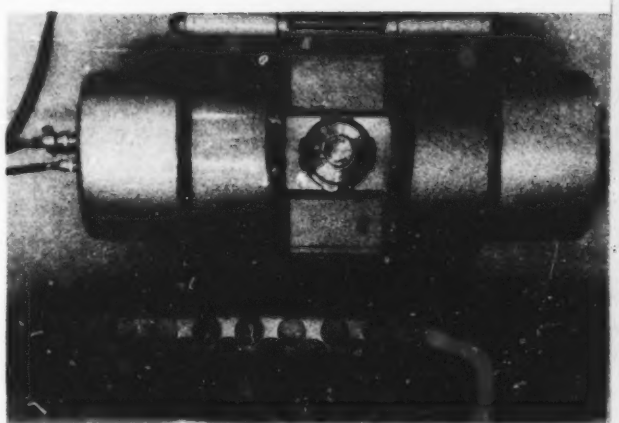

Figure 16. Liquid scintillation spectrometer - interior view, showing sample chamber enclosed by 2" lead shield. The two photomultiplier tubes are at each end of the sample chamber.

The background on the instrument varies depending on the scintillating solution, voltage tap, etc. Some background values obtained under varying conditions are tabulated below:

High Voltage Tap	Background, cpm* 10-50	10-100	10 ∞	Remarks
H V 9		50.1±0.4	98.5±0.6	"611" solution-(6 pt. dioxane, 1 pt. anisole, 1 pt. dimethoxyethane) plus 20% water. PPO and POPOP added.
H V 9		43.8±0.4	88.1±0.6	Bell's solution-(10 pt. dioxane, 0.5 pt. naphthalene) plus 10% water. PPO and POPOP added.
H V 9		109.0±0.6	166.8±0.8	From Packard Instrument Company.
H V 7	15.3±0.2	21.6±0.2		Tri-Carb (Shutter open, Sample Chamber empty).
H V 7	44.1±0.4	53.8±0.4		Tri-Carb (Empty vial).

* At discriminator settings indicated.

SHIELDING PROPORTIONAL CONVERTER

Several of our proportional counters have 2" lead-shielded converters. These units reduce the background in the beta region from about 50 cpm for an unshielded converter to about 25 cpm or less. They are used for low activity samples. Although samples must be treated to make them conducting, if they are not already so, the instruments permit a 2π counting geometry desirable for counting low activity samples.

The unit consists of a shielded chamber and preamplifier mounted in the same chassis. A 2500-volt power supply is required for the high voltage in the chamber, plus power for the preamplifier. Most commercially available scalers have the required power.

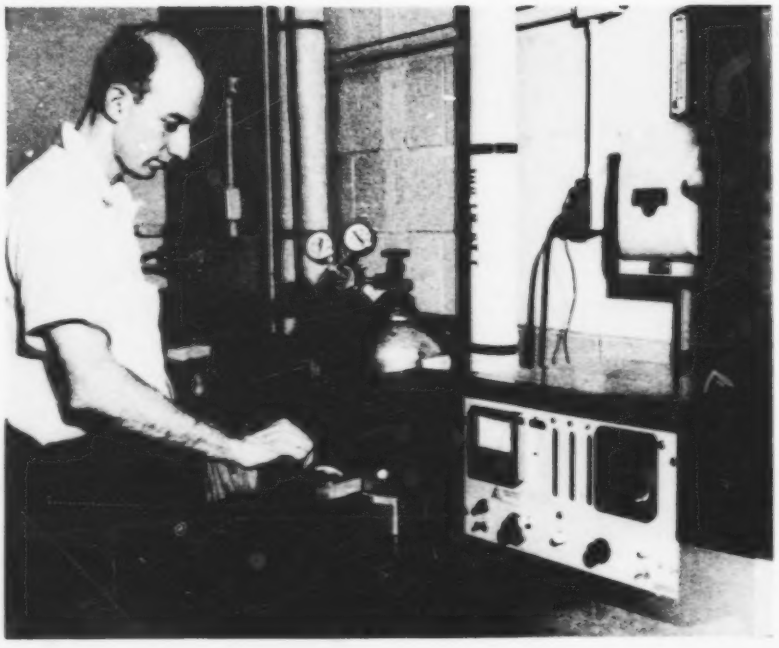

Figure 17. Shielded proportional converter.

Figure 17 illustrates the counter and shows a sample being inserted in the shielded converter. This instrument has a background of 20-30 cpm, depending on its location.